DOI 10.5162/SMSI2025/A6.4

Flexible Magnetoresistive Sensors for Novel Applications

Alberto Nicolicea[1], Eduardo Sergio Oliveros-Mata[2], Yevhen Zabila[2], Denys Makarov[2], Matthias Pelkner[1], Michael Melzer[1]
[1] Bundesanstalt für Materialforschung und -prüfung, Division 8.4 Acoustic and Electromagnetic Methods, Unter den Eichen 87, 12205 Berlin, Germany
[2] Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, Bautzner Landstraße 400, 01328 Dresden, Germany
Alberto.Nicolicea@bam.de

Summary: Recent developments in flexible electronics have lead to the appearance of flexible magnetic field sensors produced by thin-film deposition on flexible substrates which show promising capabilities for applications such spatial navigation, micro-fluidic particle detection, biomedical applications, intelligent textiles and non-destructive testing. In this work flexible anisotropic magnetoresistive sensors were used to scan curved and flat ferromagnetic samples with reference defects. Defects with depths down to 110 µm were detected with an signal-to-noise ratio of 2.7. A 2D magnetometer mapping of the surface of the samples was also obtained.

Keywords: Flexible magnetic field sensors, Flexible Electronics, Non-Destructive Testing, Thin Film Sensor Fabrication, Defect Detection

Introduction

Flexible electronics is an emerging field that has been gaining a lot of attention in recent years, with the appearance of flexible solar panels, screens and other such novel devices. Recent developments in this area have lead to the appearance of flexible magnetic field sensors which are produced by thin-film deposition on flexible substrates. These devices show promising capabilities for several applications such spatial navigation, micro-fluidic particle detection, biomedical applications and intelligent textiles [1]. One possible field of interest is the application of these devices for electromagnetic (EM) non-destructive testing (NDT), since it would enable in-contact scanning of surfaces with arbitrary shapes.

The novelty of this work consists of employing flexible anisotropic magnetoresistive (AMR) sensors mounted on a rotative mechanical holder to scan a semi-circular ferromagnetic sample with 3 reference defects via magnetic flux leakage (MFL) testing, thus demonstrating the applicability of this new method for the scanning of curved surfaces [2]. A flat ferromagnetic sample with 10 reference defects of different depths was also scanned employing flexible AMR field sensors. Defects with depths ranging from 110 µm up to 2240 µm were detected with an signal-to-noise ratio (SNR) of 2.7 up to 27.9. A 2D magnetometer mapping of the sample with a spatial scanning step of 10×50 µm^2 was also obtained using the flexible AMR sensors. This approach can be further extended to Eddy current testing, and structural health monitoring. In addition, sensor arrays and matrices can be fabricated to improve the scanning applicability.

Methodology and Results - NDT Scanning

In our study we employed flexible linear AMR sensors for MFL testing, fabricated with standard thin-film fabrication processes (photo-lithography and magnetron sputtering deposition) (Fig. 1a-b) and encapsulated with a layer of plastic lacquer which protects from corrosion. These sensors have an in-plane sensitive direction perpendicular to the magnetic bars (Fig. 1c) and their signal response is linearized by the barber-poles present in the gold layer (Fig. 1d).

To display the capability that these flexible sensors have for curved surface scanning, a semi-cylindrical ferromagnetic steel component with 3 reference defects along its surface was used (inset of Fig. 1e). Magnetization of the sample was performed diametrically. To scan this sample, the sensor is mounted on a rotative holder that also has the ability to move vertically along the z-axis. These two free axes of movement of the holder combined with the gravitational weight maintain the sensor conformal in contact with the curved sample surface during the motorized line-scans along the x-axis. Repeated scans for different positions along the y-axis produce an automated 2D magnetic mapping (Fig. 1f), with a scanning resolution of ($\Delta x \times \Delta y$) = (5×50 µm^2). The sensor-to-surface distance corresponds to the thickness (20 µm) of the flexible substrate (Kapton). A geometrical transition between the linear coordinates of the mechanical scanner and the cylindrical coordinates of the sensor was performed for the display of the signal.

A flat steel sample with several reference defects of decreasing depth was also scanned using a flexible AMR sensor, with the objective of studying the relation between defect depth the signal amplitude detected by the sensor. Once again, the steel plate was magnetized

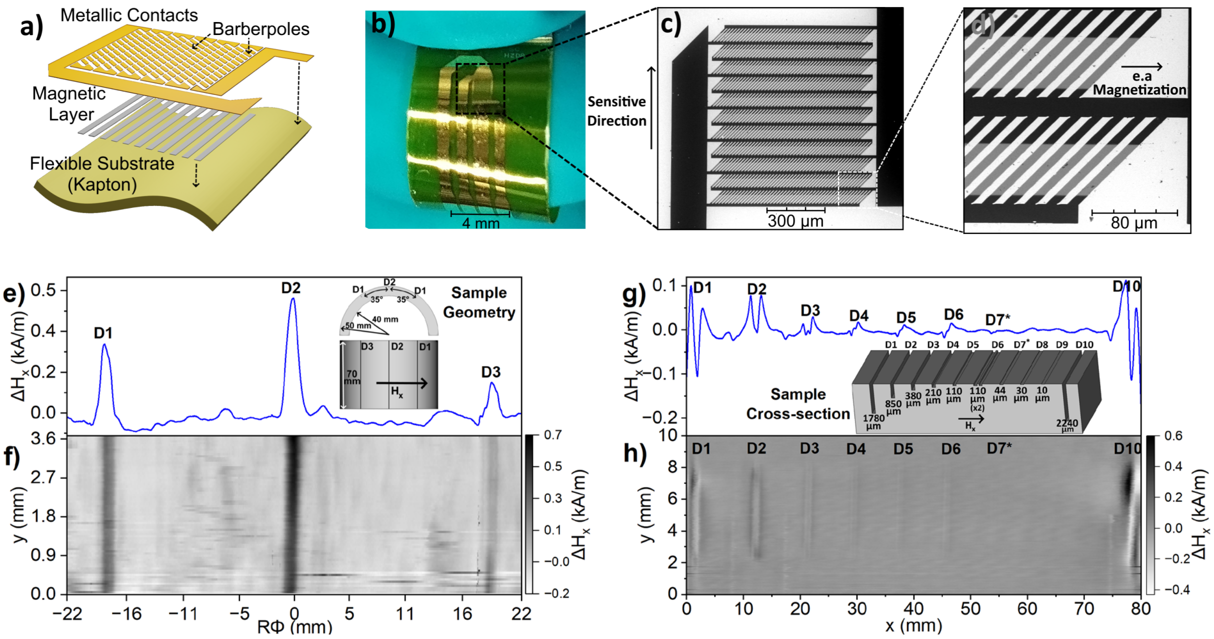

Fig. 1: Flexible AMR sensor: a) The magnetic layer of the sensor is deposited on a flexible substrate (Kapton), followed by the deposition of a gold layer forming the barber-pole structures and the electrical contacts. b) Photography displaying the flexibility of the sensor. c) Scanning electron microscopy (SEM) of the sensitive region (1 mm^2). d) SEM image focusing on the magnetic bars and the metallic barber-poles deposited on top. Scanning of a curved sample with reference defects: e) Average of 70 measurements, showing the signal amplitude of each defect. Inset shows the geometry of the sample scanned. f) 2D magnetometer scanning (cylindrical coordinates). Scanning of a flat sample: g) Levelled plot of the average centre-line signal (100 measurements). Inset showing the depth of defects (cross section view). h) 2D magnetometer mapping of the tangential magnetic field (ΔH_x). (at the limit of detection). Source: [2]*

close to saturation with a DC magnetic field directed along its length (perpendicular to the linear reference defects), before scanning. Fig. 1g) shows the average of the center-line signal of 100 scanned lines. The full-area 2D magnetometer mapping of the sample surface with an area of 10 × 80 mm^2 and a spatial scanning step of ($\Delta x \times \Delta y$) = (10 × 50 µm^2) was also obtained - Fig. 1h).

It is observed that deeper defects produce a stronger signal response when compared to more shallow ones. Defects down to 44 µm were detected, with defects D8 (30 µm) and D9 (10 µm) not detectable. Unfortunately, the AMR sensors used could not separate the signals from the double notch defect D6, since their separation distance was small compared to the sensor area. This can be fixed by further miniaturizing the sensors so as to increase the spatial resolution and capability of detecting more localized magnetic fields, since larger sensors average the signal beneath their area. However, this process might also affect the performance and characteristic parameters of the sensors. This is a future study to be performed.

Acknowledgements

This research work was funded in the framework of the BAM-internal funding instrument ”Menschen – Ideen; Ideen: Entwickeln” (”People - Ideas; Ideas: Develop”). This work is also financially supported via the European Union’s Horizon Europe Research and Innovation Programme, Grant Agreement # 101070066 (project REGO) and ERC grant 3DmultiFerro (Project number: 101141331).

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